Agriculture

Environmental Profile of Brazilian Green Coffee

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Abstract

Goal, Scope and Background. Brazil is the world's biggest producer of coffee beans with approx. a 30% market share. Depending on climate conditions, approx. 30 million bags of coffee beans are exported annually from Brazil, while domestic consumption is around 10 million bags, which makes Brazil the world's third largest coffee-consuming country. Therefore, the goal of this paper is to present the LCA of green coffee produced in Brazil for the reference crops 2001/02 and 2002/03 in order to generate detailed production inventory data as well as to identify the potential environmental impacts of its tillage in order to realize how to reduce those impacts and increase the environmental sustainability of this product. Only the inputs and outputs relative to the coffee tillage were considered. The production of fertilizers, correctives and pesticides were not included in the boundary, but only their amounts. The functional unit selected for this study was 1,000 kg of green coffee destined for exportation.

Methods. The LCI was performed according to the ISO 14040 standard series. All information considered in this study (use of water, fossil based energy, fertilizers and chemicals) were taken up in in-depth data collection and evaluation by questionnaires applied on a farm level and/or received by mail. Four Brazilian coffee producer regions were evaluated: Cerrado Mineiro, South of Minas Gerais State, the Marília and Alta Mogiana regions in São Paulo State. These regions have the following geographic coordinates: 44 to 50° W longitude and 18 to 24° S latitude. The data refer to a production of 420,000 coffee bean bags and a productive area of approx. 14,300 ha. The varieties of coffee beans considered in this study were Mundo Novo, Catuaí (yellow and red), Icatu (yellow and red), Catucaí (yellow and red) and Obatã. Farm specific data along with agricultural production data have been combined to elaborate a coffee cultivation inventory, which will be applied in an emissions estimation.

Results and Conclusion. The production of 1,000 kg of green coffee in Brazil requires approx. 11,400 kg of water, 94 kg of diesel, 270 kg of fertilizers as NPK, 900 kg of total fertilizers, 620 kg of correctives, 10 kg of pesticides and 0.05 hectare of annual land use. Outputs related to these functional units are approx. 3,000 kg of waste water from coffee washing, 8,500 kg of waste water from the wet method and 750 kg of organic residue that is reincorporated to the tillage as fertilizer. The publication of an LCI of agricultural products is a fundamental step for understanding the potential environmental impacts of each tillage and then establishes the basis for product sustainability. In this way, this work is the first Brazilian initiative for applying LCA to coffee cultivation.

Recommendation and Perspective. Different agricultural practices demonstrate different environmental profiles. The amount of agricultural pesticide is directly related to agricultural practices as tillage rotation, density of plants, etc. This study supplied important results for a better correlation of the agricultural practices and potential environmental impacts of coffee. Future updates of this study will show the evolution of the natural resource management such as land use, new agricultural practices, lower fertilizers and chemicals use.

Keywords: Agricultural products; Brazil; green coffee; life cycle inventory (LCI); sustainability

Introduction

The world coffee bean market is characterized by the presence of sixty coffee producing countries. Brazil and Colombia together command approximately half of the world market, while the remaining countries have small market shares. Brazil is the world's biggest producer of coffee beans in terms of cultivated area and bag production with approx. a 30% market share. Depending on climate conditions, approx. 30 million bags of coffee beans are exported annually from Brazil, while domestic consumption is around 10 million bags, which makes Brazil the world's third largest coffee-consuming country. Considering the year 2002 as a reference, the Brazilian coffee production (*Coffea arabica*) was 48,480,000 bags, representing 40.6% of the world's exportation (Cecafé 2004).

Five states produce coffee in Brazil (Minas Gerais – 50.8%, Espírito Santo – 20.1%, São Paulo – 12.4%, Paraná and Bahia) with several differences in all the production aspects (Aguiar 2001, Igreja and Bliska 2002, Fazuoli et al. 1999, Kashima 1990, Verdade et al. 1974), being the main aspects described below:

1. **Size of the coffee production areas.** Ranging from a few (familiar properties) to a thousand hectares (company properties) giving diverse producer profiles;
2. **Edafoclimatic differences among the cultivation regions.** Cultivation areas are mainly located between 10–24° S latitude and 40–54° W longitude and show various climate types (semi-humid hot, semi-humid sub-hot, humid sub-hot, super-humid sub-hot, sub-dry and meso-thermic);

3. **Cultivated varieties.** The main varieties cultivated in the evaluated regions are Mundo Novo, Catuaí (yellow and red), Icatu (yellow and red), Catucaí (yellow and red), Obatã, Acaiá and Tupi;

4. **Adopted spacer.** Ranging from traditional (4.0 x 2.5 m) and mechanical harvest (3.5 x 0.7 m) to more compact tillage (2.5 x 0.7 m);

5. **Coffee cultivation management.** Chemical use (type and quantity) and crop type (manual or mechanical);

6. **Local topography conditions.** Agricultural machinery and implement use, and adopted spacers;

7. **Coffee production and processing technology.** Producer revenue and technico-scientific information, besides socio-economical resources and development of the property.

Besides the above geographical factors influencing the coffee quality, the preparation process also directly affects the product quality. There are two coffee preparation methods: the dry method and wet method. Both methods have the following common stages: cleaning, separation, drying, storage, processing and classification (**Fig. 1**). Additionally, the wet method includes the separation of red coffee berries, pulp remotion, mucilage removal and product washing. In the dry method, the processing stages for preparing the yard coffees can be performed without the use of water. However, the use of water is essential in the wet method for obtaining the washed coffees or coffees without pulp (Alves 1999, Filho et al. 2002, Andrade et al. 1999, Nannetti 1999a–c, Thomaziello 2000a–b, Zambolin 2000).
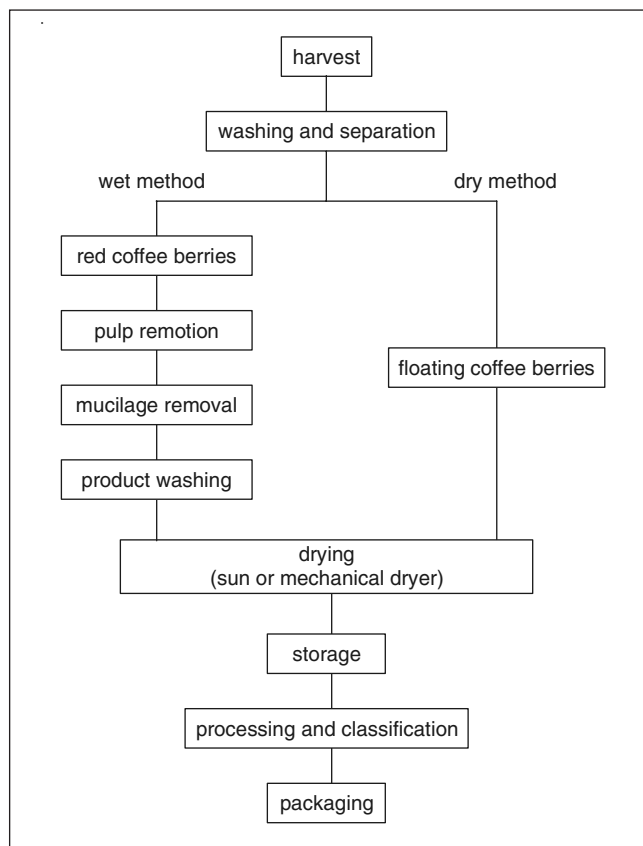

Fig. 1: Flowchart of coffee processing, showing the two coffee preparation methods (dry method and wet method)

Nowadays there is no environmental criteria established for ecolabel in Brazil, despite the efforts of conducting an LCA of leather in the southern region of Brazil at the beginning of 2000s in order to establish environmental criteria for the ecolabel of shoes. There is a tendency to consider the whole life cycle of the product for the establishment of the environmental criteria for the ecolabel (Canals et al. 2002). Thus, this study was the first LCA conducted for the establishment of an environmental profile of coffee cultivation in Brazil as a basic criteria for the sustainability of green coffee.

Food productivity had increased significantly due to new technologies, mechanization, chemical use and governmental policies. However, together with the positive effects on farming, some impacts like degradation of soil and water resources also occur. For instance, the excessive application of fertilizers (quantity and frequency) usually exceeds the soil ability to retain and transform the nutrients and make them available according to the crop needs. According to some studies, the saturation of the soil with nitrogen or phosphate has promoted losses of nitrates into groundwater and saturation of the soil with phosphate, that may also move into groundwater. Regarding pesticide use, these products on a farm level can cause the destruction of part of the soil flora and fauna, that in turn causes both physical and chemical deterioration (Cowell and Cliff 1997, Mattsson and Sonesson 2003, Zalidis et al. 2002). Then, a good control of the amount of inputs added to the tillage is very important from both an environmental aspect and from economic point of view.

According to Salomone (2003), the main categories of environmental impact verified in a life cycle assessment study applied to coffee production in the stage of coffee cultivation were eutrophication (320 g.eq PO_4^{3-}/kg of packed coffee) and terrestrial ecotoxicity (approx. 6 t/kg of packed coffee). In this study, the author included all life cycle stages from coffee cultivation through its distribution to consumers, consumption and disposal, aside from fertilizer and pesticide production data employing commercially available databases.

Nevertheless, there are also positive effects of agricultural activities in terms of biodiversity protection, carbon capture and oxygen generation. For instance, it was estimated that coffee plants capture approx. 35% as much of the carbon dioxide as the same area of woodlands (Pelupessy 2003).

1 Goal and Scope

The goal of this paper was to present the LCI of green coffee produced in Brazil for the reference crops 2001/02 and 2002/03 in order to obtain detailed production inventory data, as well as to quantify the potential environmental impacts of this tillage in order to realize how to reduce those impacts and increase the environmental sustainability of this product.

The scope of this work was to qualify and quantify the main environmental aspects of the green coffee production in Brazil in order to establish parameters for the sustainability and a future ecolabelling program for the Brazilian green coffee. Thus, the users of the information provided by this study are the coffee growers, the coffee growers' association and the governmental agencies towards getting best practices going in accordance with the environmental sustainability of Brazilian coffee.

The adopted functional units were the production of 1,000 kg of green coffee destined for exportation and 1 hectare of harvested area. These units are not related to the function of the green coffee, since the use stage was not included in the system. Thus, the cradle to gate LCI basis was adopted.

2 Methods

This study has been conducted in accordance with the recommendations of the International Standard ISO 14040 (1997) – Environmental Management – Life Cycle Assessment – Principles and Framework.

The following impact categories were selected for the study: depletion of fossil energy resources, depletion of natural resources; climate change; acidification; nutrification; human toxicity; ecotoxicity and land use. The data collection for the LCI of green coffee was carried out taking into account the impact categories selected for the study. Data storage and modeling were performed by means of the PIRA Environmental Management System – PEMS4 software purchased from Pira International.

All information considered in this study (use of water, fossil based energy, fertilizers and chemicals) was taken up in-depth data collection and by questionnaires applied on farm level

and/or sent by mail. A total of 56 properties located at four Brazilian coffee producer regions were evaluated: Cerrado Mineiro and South of Minas Gerais regions in Minas Gerais State, Marília and Alta Mogiana regions in São Paulo State. These regions have the following geographic coordinates: 44 to 50° W longitude and 18 to 24° S latitude. The data refer to a production of approx. 420,000 coffee bean bags and a productive area of approx. 14,300 ha. The varieties of coffee beans considered in this study were Mundo Novo, Catuaí (yellow and red), Icatu (yellow and red), Catucaí (yellow and red) and Obatã. Farm specific data along with agricultural production data have been combined to construct a coffee growing model, which has been applied to emission estimations.

Only the inputs and outputs relative to the coffee tillage were considered in this study as a cradle-to-gate system. The production of fertilizers, correctives and pesticides were not included in the boundary, but only their amount, as well as the transportation of them to the farms.

3 Results and Discussion

Table 1 shows the main inputs and outputs of the life cycle inventory of the coffee growing in Brazil for the functional unit of 1,000 kg of green coffee. These data reflect the cul-

Table 1: Summary of the Brazilian life cycle inventory for 1,000 kg of green coffee production for the reference crops 2001/02 and 2002/03

Parameters	Unit	Weighted Average	Arithmetic Average	Maximum	Minimum	'Surplus index'
Input						
Energy						
Total	MJ	10,670	12,195	66,566	3,824	5
Electric (public grid)	MJ	646	533	1,934	36	4
LPG	kg	6	26	49	5	2
Wood	kg	368	782	6,350	29	8
Diesel	kg	94	77	331	5	4
Other Resources						
Water for coffee processing	kg	11,437	10,160	60,000	72	6
Fertilizers						
Total [a]	kg	911	1,160	3,583	11	3
N, P, K	kg	274	318	927	1.26	3
B, Cu, Fe, Mn, S, Zn	kg	6	8	33	0.19	4
Pesticides						
Total [a]	kg	10	10	30	0.73	3
Fungicide	kg	1.72	1.06	6	0.01	6
Herbicide	kg	1.15	1.49	12	0.13	8
Inseticide	kg	0.98	1.51	11	0.02	7
Bactericide	kg	0.14	0.72	0.98	0.40	1
Acaricide	kg	0.35	0.48	1.11	0.02	2
Acaricide/ Inseticide	kg	0.002	0.09	0.13	0.06	1
Correctives						
Total [a]	kg	622	749	4,480	200	6
Ca, Mg	kg	273	320	1954	0.01	6
Land Use						
Land use [b]	ha.a	0.05	0.05	0.1	0.03	2
Output						
Organic residue used as fertilizer	kg	757	758	758	752	1
Waste water (coffee washing)	kg	2,901	5,803	60,000	72	10
Waste water (wet route)	kg	8,535	6,808	15,277	2,618	2

Surplus index = Maximum value divided by the arithmetic average
[a] Total = Active and filler elements
[b] 12 years was considered as the life time of the profitable harvest for calculating the hectare of annual land use

tivation profile of 56 coffee farms grouped in 28 questionnaires. The table**s** presents the arithmetic average and the weighted average, i.e. the productive contribution of each cooperative and of each farm to the average of the evaluated sample, respectively. As can be seen, the results show a large variation among the data, being the greater variation observed for the waste water from the coffee washing at the coffee processing stage.

The total energy (10,670 MJ/1,000 kg of green coffee) accounts for the extraction of the oil and the production of the specific fuels considering the upper calorific value of them. Energy is required both in the growing and in the processing stages. Diesel consumption is due to the fuel use by the agricultural machinery and the considered transport stages. Wood and electric energy are used mainly in the coffee processing and the coffee bean drying, in order to reduce the moisture content of the product up to 11%. Only 6 interviewees employed LPG for these purposes.

A proportion of 11:1 of water consumption for 1,000 kg of green coffee was found showing a significant use of this natural resource. The water quantified in this study is the amount of fresh water used in the coffee processing stage for both coffee washing and the wet method. Since water is the future scarce resource, this consumption should be evaluated properly.

Coffee cultivation requires the use of fertilizers as sources of macronutrients like N, P and K, and also of micronutrients such as S, Fe, Mn, Cu, B and Zn. These elements are mainly supplied to the tillage in the form of inorganic salts such as urea, phosphates, boric acid, KCl, KNO_3, $MnSO_4$, $CuSO_4$, $ZnSO_4$, ZnO, etc. As shown in Table 1, the total mass of fertilizers (active and filler elements) added to the crop is approx. 3 times higher than the mass of the required active elements.

The total mass of correctives added for the production of 1,000 kg of green coffee was 622 kg. Limestone is the most usual Ca and Mg source. These elements have a significant participation in the coffee grain composition besides their use for correction of the soil acidity.

Fungicides and herbicides followed by insecticides are the main classes of pesticides used. All the inventoried pesticides are approved for coffee cultivation in terms of both type and quantity.

Organic residue from the coffee processing was 757 kg / 1,000 kg of green coffee. This amount of residue is derived from the low fraction of the harvested coffee, that is the coffee bean itself (approx. 4:1). This organic residue, the outer hull, is further reincorporated to the tillage soil as fertilizer since it is rich in mineral and organic compounds.

The 'surplus indexes' shown in Table 1 indicate that the maximum value of each input ranges from 1 to 10 times the average values. Although the use of fertilizers and pesticides depends on the specific needs of each agricultural unit, these great differences evidence a clear opportunity for the reduction of these inputs.

Table 2 shows the main inputs and outputs of the life cycle inventory of the coffee growing in Brazil for the functional unit of 1 hectare of harvested area. According to this functional unit, two main aspects can be highlighted: the economic efficiency and the environmental performance (see Table 2). Both of these aspects are quite different among the evaluated coffee growers.

The quantity of pesticides is lower while the amount of fertilizers used in the present study is higher than the quantities verified by Diers et al. (1999) in their study about LCA of roasted coffee (23 kg pesticides and 600 kg fertilizers per hectare). According to the authors, this 600 kg mineral-dung contains 100 kg of nitrogen (N), 50 kg of phosphates (P_2O_5) and 80 kg of potassium (K_2O) as nutrients. These differences probably are related to the geographical characteristics and production aspects of the studied coffee regions, since that study evaluated coffee from Costa Rica.

A wide range of crop characteristics was observed among the evaluated farms (**Table 3**). The adopted plant density varied from 1,000 to 5,500 plants per hectare as a consequence of the local topography conditions, adopted space among plants, etc. Afterall, production systems with low (780 kg/ha) and high (2580 kg/ha) yields participated in this study. However, the areas included in the inventory had similar pluviometric indexes, ranging from approx. 1,200 to 2,000 mm/year.

The main environmental impacts of these inventoried data will be evaluated in a coming paper.

Improvement of the sustainability of Brazilian green coffee. One of the main goals for conducting this study was to measure the actual environmental profile of the coffee cultivation sector in order to establish a scientific basis for a future implementation of environmental labeling for this product. So, the data supplied by this study will help the coffee growers, the coffee growers' association and the governmental agencies towards getting best practices going in accordance with the environmental sustainability of the Brazilian coffee.

Input reduction is the first principle for sustainability of any process. Analyzing the amount of added fertilizers (**Fig. 2**) or pesticides (**Fig. 3**) as a function of the productivity of each evaluated farm showed no direct correlation of these inputs to the yield obtained by the individual growers. Nevertheless, it was possible to identify three farms that combine a simultaneously high yield with a low consumption of fertilizers and pesticides (circled values in Fig. 2 and 3). So, from this evaluated sample, these three producers can be considered the most environmentally friendly and efficient coffee growers.

Due to the broad dispersion of data showed by the farms, a detailed analysis of these data together the coffee growers is being planned for the discussion of better practices in order to improve the environmental profile of the Brazilian coffee growers sector with environmental and economical benefits.

Table 2: Summary of the Brazilian life cycle inventory for 1 hectare of green coffee production for the reference crops 2001/02 and 2002/03

Parameters	Unit	Weighted Average	Arithmetic Average	Maximum	Minimum
Input					
Energy					
Total	MJ	18,736	21,254	137,292	8,050
Electric (public grid)	MJ	1,184	941	3,132	57
LPG	kg	13	52	107	8
Wood	kg	650	1,401	13,097	62
Diesel	kg	161	127	427	8
Other Resources					
Water for coffee processing	kg	20,312	18,385	121,976	157
Fertilizers					
Total [a]	kg	1,625	1,992	7,143	26
N, P, K	kg	497	557	1,713	3
B, Cu, Fe, Mn, S, Zn	kg	11	15	56	0.3
Pesticides					
Total [a]	kg	15	18	50	1.2
Fungicide	kg	3	1.9	9	0.02
Herbicide	kg	2	2	9	0.2
Inseticide	kg	1.6	2	17	0.03
Bactericide	kg	0.2	1.2	2	0.7
Acaricide	kg	0.6	0.9	2	0.03
Acaricide/ Inseticide	kg	0.003	0.2	0.2	0.1
Correctives					
Total [a]	kg	1,057	1,238	5,774	333
Ca, Mg	kg	465	532	2,519	0.02
Output [b]					
Organic residue used as fertilizer	kg	1,370	1,363	1,937	595
Waste water (coffee washing)	kg	5,283	10,683	121,976	157
Waste water (wet route)	kg	15,029	12,035	28,373	3,803

[a] Total =Active and filler elements
[b] LAND USE = 0.08 ha.a

Table 3: Crop characteristics of the evaluated coffee growing farms

Parameters	Unit	Arithmetic Average	Maximum	Minimum	'Surplus index'
Crop Characteristics					
Productive plants	Plants	1,775,150	10,109,791	70,000	6
Plant density	Plants/ha	3,184	5,556	1,000	2
Yields	kg/ha	1,800	2,580	780	1
Pluviometric data	mm/year	1,515	1,990	1,183	1

Surplus index = Maximum value divided by the arithmetic average
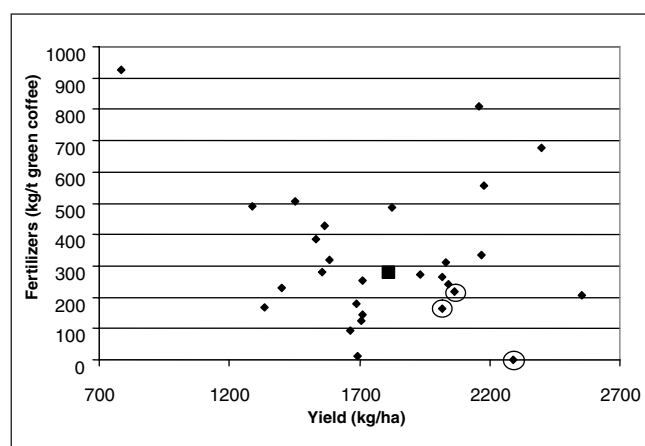
Fig. 2: Consumption of fertilizers (N, P, K and other elements) in relation to the green coffee yield for the reference crops 2001/02 and 2002/03. The highlighted value shows the weighted average
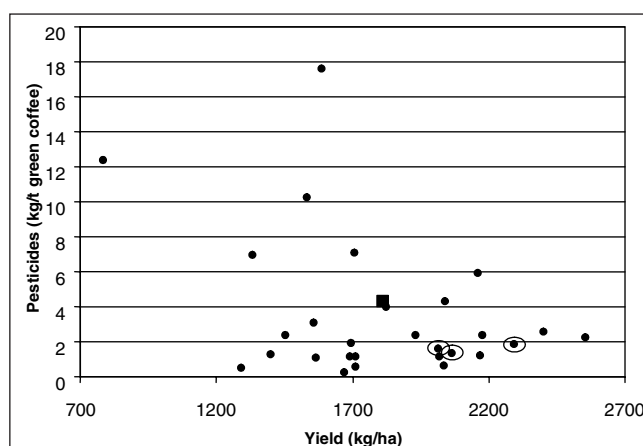
Fig. 3: Consumption of pesticides (mass of active elements) in relation to the green coffee yield for the reference crops 2001/02 and 2002/03. The highlighted value shows the weighted average

4   Conclusions

To conduct LCA of agricultural products is a very complex task taking into account the data acquisition, modeling and compilation. However, the publication of LCA of agricultural products is a fundamental step for understanding the potential environmental impacts of each tillage and then establishing the basis for product ecolabelling. In this way, this work is the first Brazilian initiative for conducting the coffee cultivation LCA.

A large variation of the amount of agricultural inputs among the participants was found. Although the use of fertilizers and pesticides demonstrates lapses of the specific needs of each agricultural unit, these great differences show evidence of a clear opportunity for the reduction of these inputs.

A detailed discussion of inventory with the players in the coffee sector is being planned in order to establish the maximum levels of energy, water, fertilizer, corrective and pesticide consumption that can be accepted to characterize an environmentally sustainable green coffee production system.

LCA associated with the climatic data will allow a sustainable management of the natural resources. Different agricultural practices produce different environmental performances. The amount of pesticides is directly related to cultivation practices such as tillage rotation, density of plants, etc.

This study will supply important results for a better correlation of the agricultural practices and potential environmental impacts of this product. Future updates of this study will show the evolution of the natural resources management as land use, new agricultural practices, lower fertilizer and chemical use.

5   Recommendations and Outlook

The next step is to discuss these results with the players of the coffee sector and the members of the Brazilian environmental management council in order to recommend the maximum consumption levels for energy, water, fertilizers, correctives and pesticides that can be accepted to characterize a sustainable green coffee production system.

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